STUDY OF EVASIVE ACTION UNDER GUNFIRE

DRAWINGS

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Drawings

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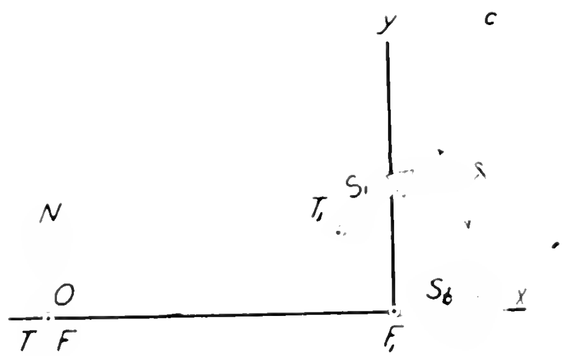

Fig. 1

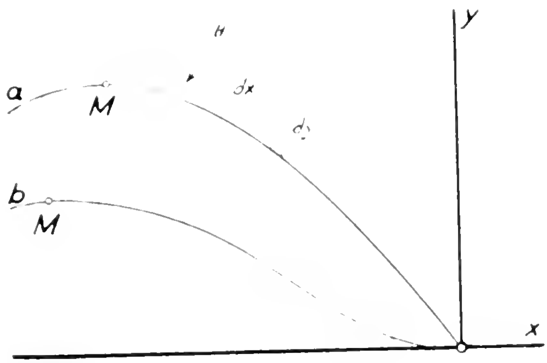

Fig 2

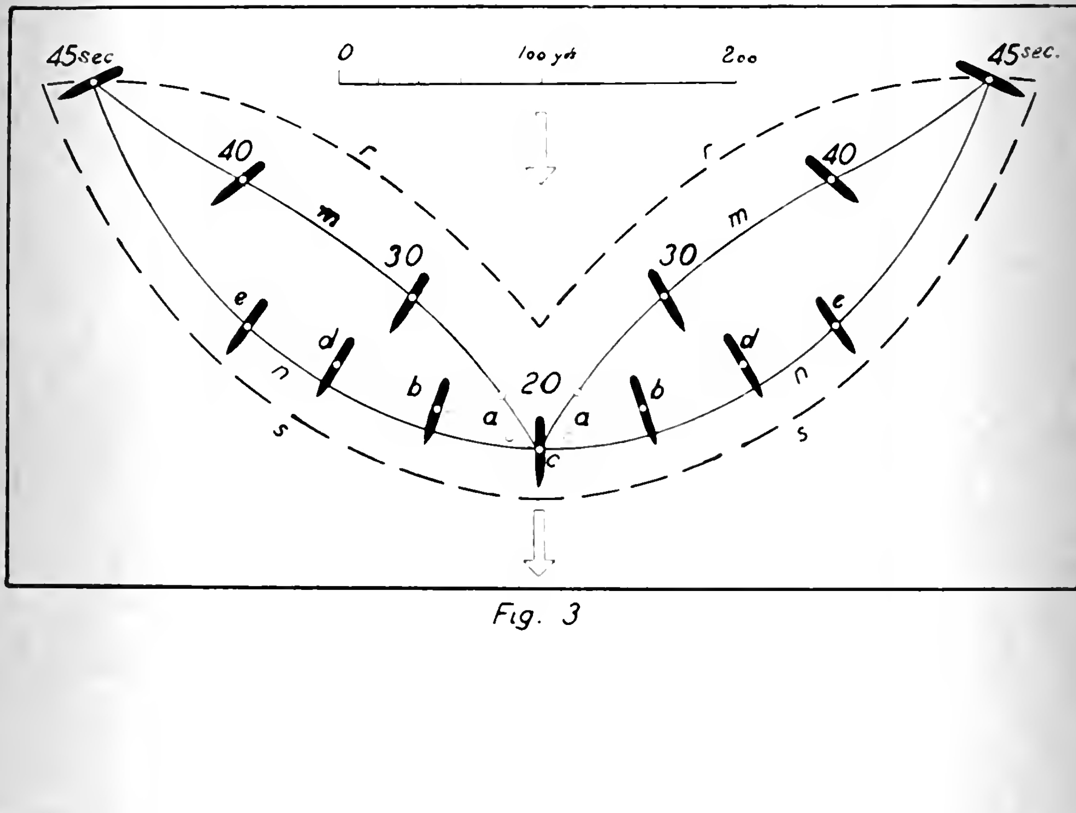

Fig. 3

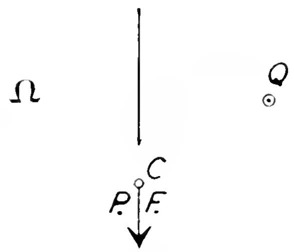

Fig. 4

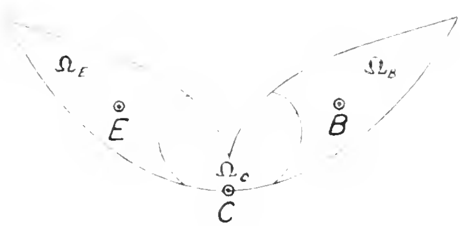

Fig. 5

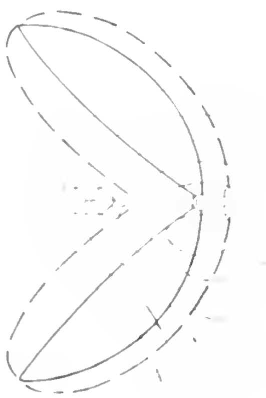

Fig. 11

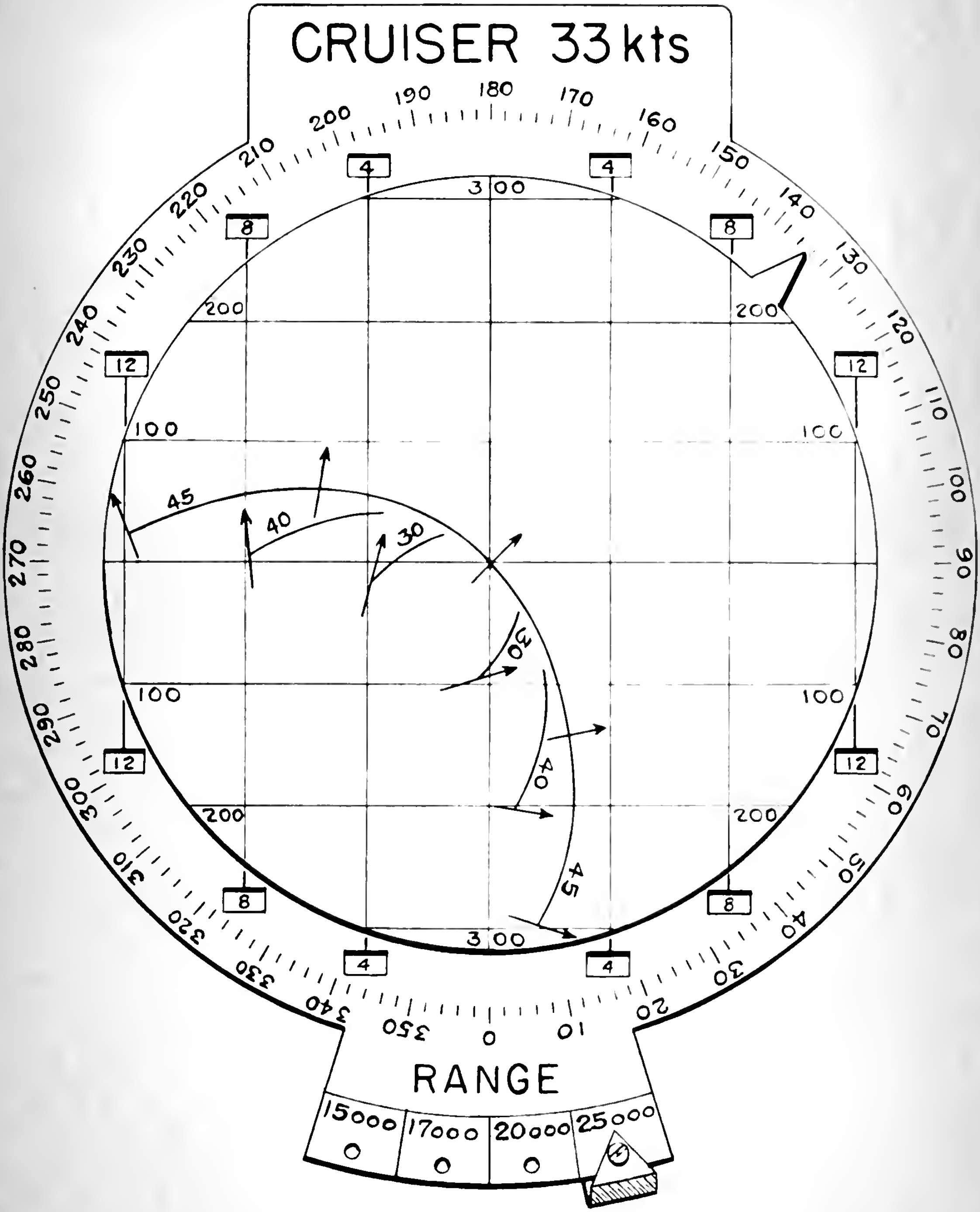

Fig. 10

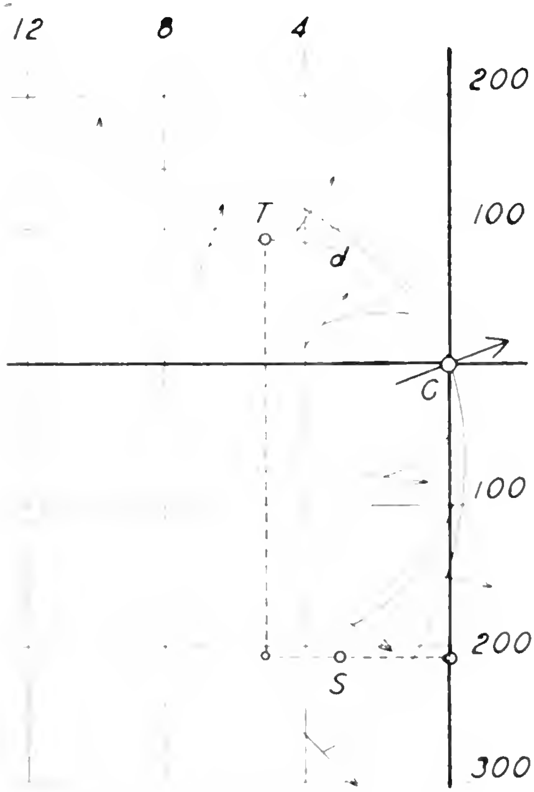

Fig. 9

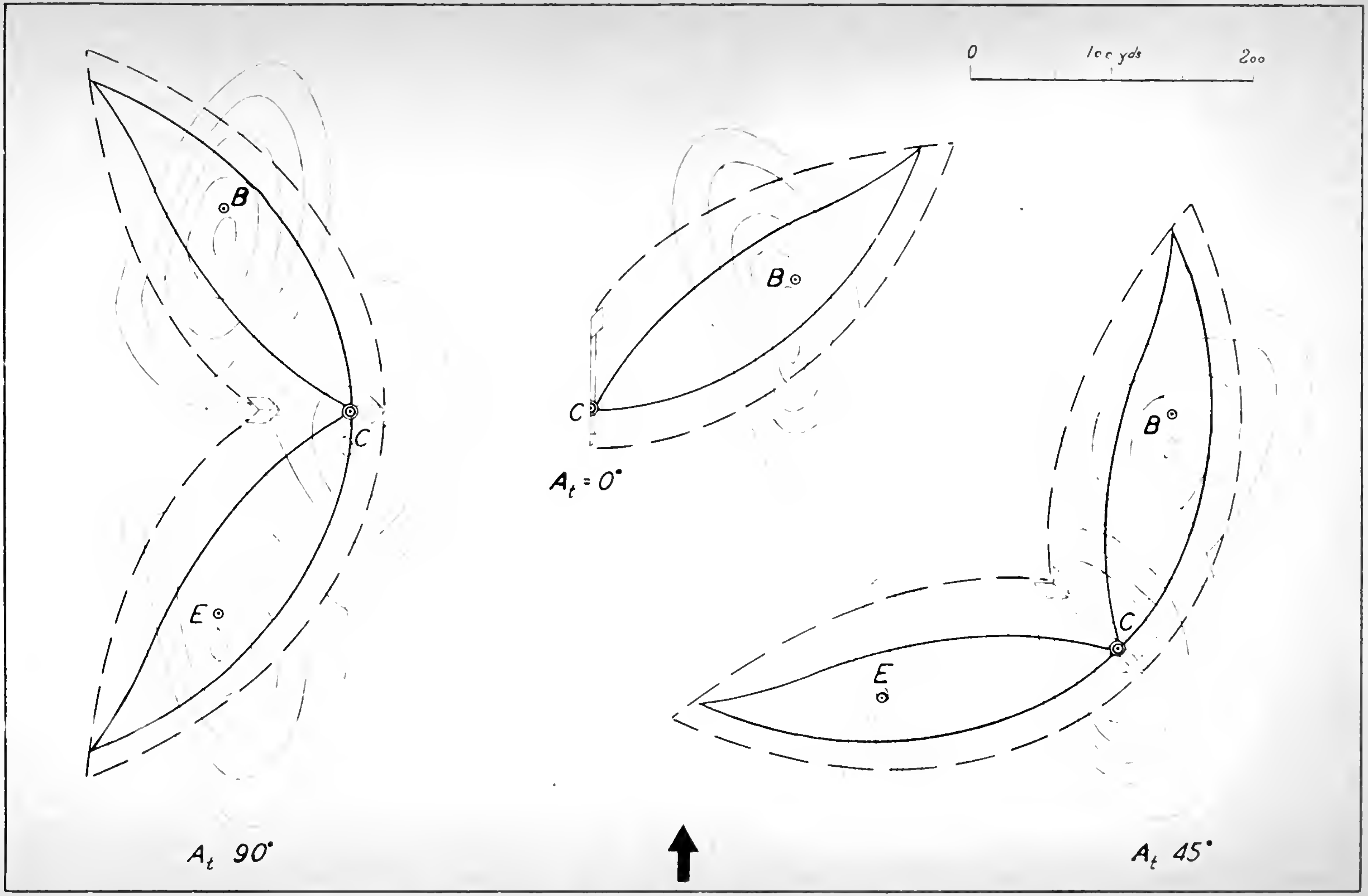

Fig. 8

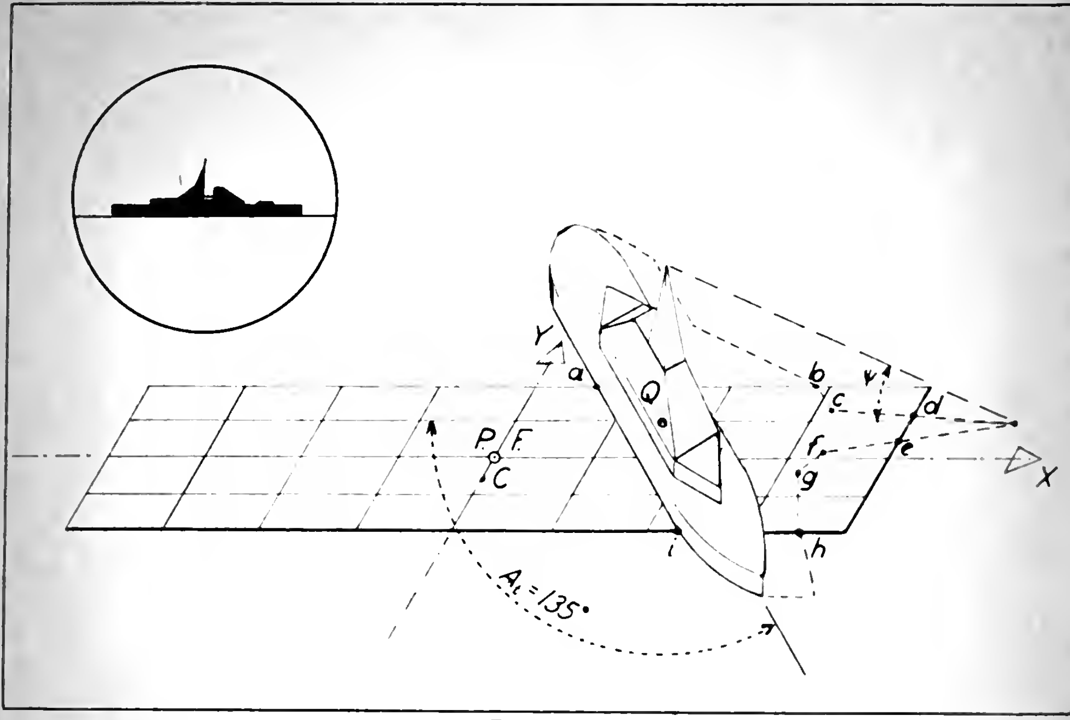
Y
a
b
c
d
Q
P
F
C
f
e
X
g
i
h
$A_t = 135°$

Fig. 6

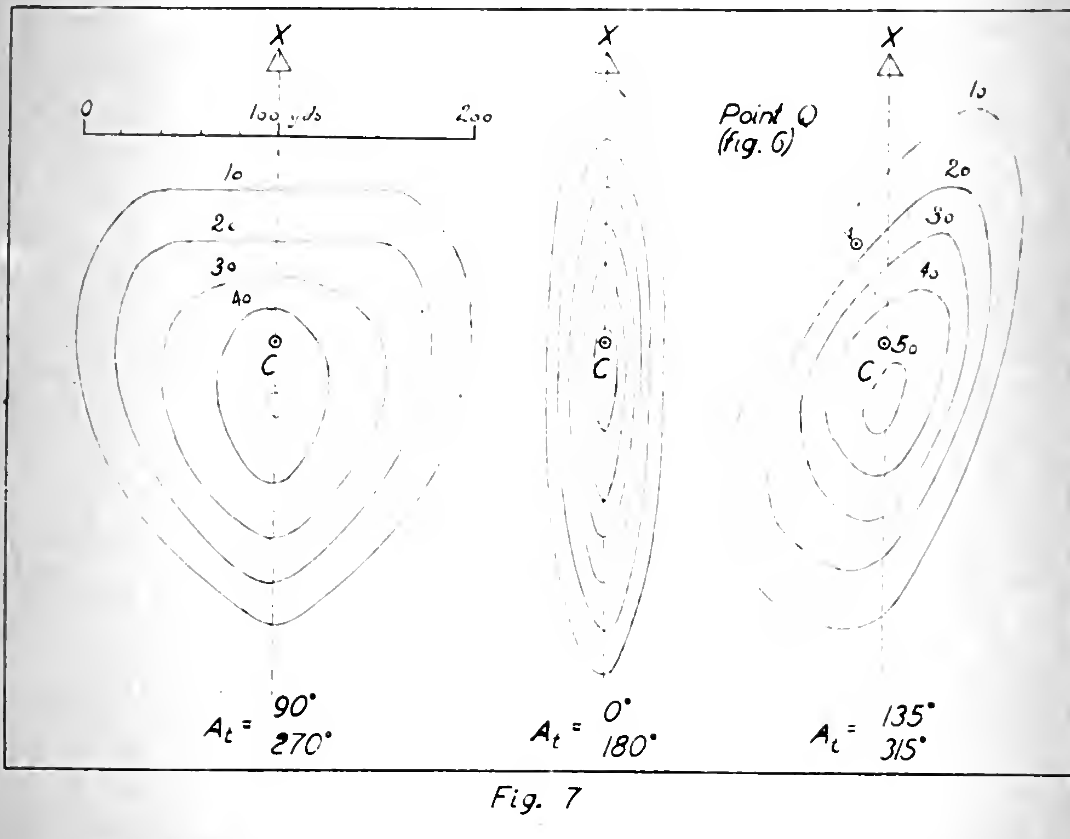
X
X
X
0
100 yds
200
Point Q
(fig. 6)
10
20
30
40
C
C
50
C
$A_t = {90° \atop 270°}$
$A_t = {0° \atop 180°}$
$A_t = {135° \atop 315°}$

Fig. 7

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By evasive action of the target,may be considered any one whose purpose is to reduce the efficiency of the enemy fire.Among the different types of evasive action,the most interesting and undoubtedly the most open to discussion is that of the maneuver.

The modern Directors determine with accuracy the range and deflection corresponding to the future position of the target,or in other words the position where it will be at the fall of a salvo,supposing that its course and speed be constantly maintained.Nevertheless,in certain circumstances the target may maneuver during the time of flight of the projectil,trying to evade the "future position" on which the enemy fire is supposed to be adjusted.

When is such an evasive action likely to occur ? - What will be the best solution in each case ? - And:up to what extent may it be counteracted ? These are problems which will hardly ever find a conclusive answer.We shall try at least to find out their principal factors,derived from the physical constants which limit the possible performances for the target as well as for the gun.These elemental factors may afterwards be considered jointly with various tactical situations,which will prevail upon the target restraining its movements,and upon the gun regulating the rate of fire.

I - Theoretical considerations

A)Target maneuvers

From the point of view of the evasive action,we must know in the first place the maneuvering capacity of the target during the time of flight of the proyectil,and its effects related to the "future position".

Let "T" and "F" be two ships (fig.1),steaming together at the same speed S_t

Upon passing through point <u>O</u>,"T" commences an evolution along the curve <u>OC</u>.

We wish to know just in which form "T" shall be separating herself from "F" while time is passing on.This having been obtained,the relative position of "T_1" with respect to "F_1" will represent the separation from the "future position" produced by such maneuver after a time t_1.If <u>OC</u> is a known curve of turn,this separation will be given in terms of loss of way (x) and lateral separation from the course (y),by the following relations:

$$\begin{aligned} x_1 &= \overline{NT_1} - t_1 S_t \\ y_1 &= \overline{NO} \end{aligned} \qquad (1)$$

In this way it is possible to transfer the set of curves of turn for a given type of ship,to the curves of fig.2 which we shall call "evasion curves".In order to know the shape of these curves for t = 0,some differential considerations are needed.As can be seen in fig.1,

$$\begin{aligned} \frac{dx}{dt} &= S \cos\delta - S_t \\ \frac{dy}{dt} &= S \sin\delta \end{aligned} \qquad (2)$$

or,by simple division,

$$\frac{dx}{dy} = \frac{\cos\delta - 1}{\sin\delta} + \frac{S_t - S}{S \sin\delta}$$

And since $\frac{dx}{dy} = -\tan\theta$ (fig.2),we have

$$\tan\theta = \tan\frac{1}{2}\delta + \frac{1}{S}\frac{S_t - S}{\sin\delta} \qquad (3)$$

At the begining of the maneuver,the shift of the bow (δ) will be zero,so that the second term pf (3) has an overwhelming influence.The limit to which said term tends when t = 0,is characteristic of the ship's reaction to the rudder action.For those ships that work well and easily,the loss of speed is very small and it occurs proportionally with the changing of course,so that tan θ will have a finite value;at small rudder angles,the

evasion curves will approach the tangent to the axis <u>oy</u>.This is the case of curve "a" in fig.2;but if an appreciable loss of speed occurs before the change of course has been initiated,as happens with heavy ships and under greater rudder angles,the value of tan θ becomes infinite when sin $\delta = 0$ (curve "b").

In fig.3 we can observe evasion curves corresponding to an average type of cruiser,at 33 knots of speed.The starting position is <u>c</u>,and with a rudder angle of 15° the ship will reach point <u>a</u> within 20 seconds,point <u>b</u> in 30 seconds,point <u>d</u> after 40 seconds,and point <u>e</u> when 45 seconds have elapsed. We can also appreciate in this figure,the shiftings of the bow corresponding to these last three positions.With a rudder angle of 35°,considered as a maximum limit,we shall have,instead,the evasion curves "m".

We shall designate "evasion area",the one which comprises all points the target might reach within a certain time of evasive maneuver.According to the foregoing considerations,the area enclosed by curves "m" and "n" will include all possible rudder maneuvers.If,besides the simple course changes, we should want to take into consideration the posibility that the target change its speed,this area would be increased by two zones,one of them back of "m" and the other ahead of "n".In our case the curves "r",which are the limits of speed-reduction zone,have been traced by computing the loss of way produced by a total stop of the engines during a period of 45 seconds. For the zone of speed-increase,we have supposed that during this short time their power may be increased up to 20%.

B)<u>Effects of the maneuver upon the probability of impact</u>.

In the following arguments,we shall call "point of fire"(P.F.)the point upon which the fire is supposedly directed.If the fire has been duly adjusted,the distribution of projectils around the P.F. will be solely governed by accidental errors,in a pattern known for any Battery and Fire

Control System. With the range and deflection data for this pattern, we can compute the simple probability of impact (p_Q), over a target placed on some point Q (fig. 4) at the instant of the fall of the projectils.

At the moment of firing the salvo, we shall ignore the exact position of the target after the time of flight; the event of being located at a point Q will have a probability

$$q \, d\Omega$$

where "q" is a variable factor (probability per unit area or "probability density factor").

Since the target is restricted to its evasion area (Ω), we can state:

$$\int_{\Omega} q \, d\Omega = 1 \qquad (4)$$

In such a case, $P = \int_{\Omega} q . p_Q . d\Omega$ (5)

If for a moment we leave aside any tactical considerations, we may assume the same value of "q" to all points, and according to (4) that value is $\frac{1}{\Omega}$.

In this case the total probability of impact given by (5) will have a particular value,

$$P' = \frac{1}{\Omega} \int p \, d\Omega \qquad (6)$$

which will depend upon the position of the pattern in the evasion area (Ω). For example (fig. 5), supposing the P.F. is over B, C, or E, then we shall obtain three distinct values:

$$P_B' \ , \ P_C' \ , \ P_E' \ ,$$

which will be an expresion of the higher or lesser degree to which the target's capacity for changing its course is checked. These values can be useful afterwards, as a basis for estimating the total probability of impact under diverse tactical situations.

First of all, let us observe that in each one of the cases described, the fire is directed to a particular fraction of the evasion area:

Ω_B ,corresponding to maneuvers effected freely to port;

Ω_C ,corresponding to a constrained evasive action;

Ω_E ,corresponding to target maneuvers to starboard without any restrictions or limitations.

Let us assign for each one of them a distinct value of "q".In such a case, formula (5) will give in the case of firing over B:

$$P_B = q_B \int_{\Omega_B} p_Q \, d\Omega + q_C \int_{\Omega_C} p_Q \, d\Omega + q_E \int_{\Omega_E} p_Q \, d\Omega$$

When firing at a long distance,because of the size of Ω_B,the value of "p_Q" will be practically zero outside of this area if B is our point of fire. Thence,according to (6) we can assume:

$$P_B = q_B \int_{\Omega} p_Q \, d\Omega = q_B \, \Omega P_B' \qquad (7)$$

In a similar way,the total probability of impact if fire is directed upon C or E will be respectively as follows:

$$\begin{aligned} P_C &= q_E \, \Omega P_C' \\ P_E &= q_E \, \Omega P_E' \end{aligned} \qquad (7)$$

Before mentioning possible applications of these calculations,we shall try to illustrate them briefly,presenting a concrete case.

II - A concrete case

As an illustration for the points treated up to now,we have selected the case of firing with heavy guns,upon a cruiser at 25,000 yds.For such a distance,we shall take a pattern of adequate size considering the effects of control errors,so that the center of this pattern will be our point of fire.Such pattern is shown in fig.6 by a rectangle subdivided into numerous cells,each one of which contains a certain percentage of shots according to the well-known law of Gauss,and giving a total of 100% for the entire pattern.The figure also shows the proceeding employed to determine the probability of impact corresponding to each position of the target (Q).That will be equal to the percentage of shots contained within the area

determined by projecting the target on the pattern,in the direction of fall of the projectil.

If we take enough points Q,varying the coordinates X and Y,then we shall be able to trace the curves of equal probability-level shown in fig.7. Therein we present three graphs,computed for six different target angles. The outer line in each one,represents the points of 10% of probability of impact;the following,the locus of 20%,and so forth.

The evasion area has been delineated taking as a basis the curves-of-turn and speed-change characteristic of this type of ship at a speed of 33 knots. Figure 3,already described,shows three different zones of this evasion area:

Z_0- zone covered with only rudder maneuver;

Z_1- zone reached combining rudder maneuver and loss of speed;

Z_2- zone reached combining rudder maneuver and speed increase, assuming that for a short time a 20% increase in the propeller power is possible.

When the target executes a rudder maneuver to elude the enemy fire,this may be performed employing the whole time of flight or only a part of it, due to any delay in the reaction.In any one of these cases,it will be at a specific point of the zone Z_0,with a specific direction of its bow,when the salvo falls.If the fire was directed over C we have then for each point within Z_0 a definite probability of impact,as a function of these two factors:position and direction of the bow.

With a similar treatment for the other two zones where a change of speed is involved,the curves of probability-level can be computed,when the fire is directed over C as well as over any other point of the evasion area.In fig.8,are presented three different charts depending upon the initial course of the target;and for each,the point of fire is assumed to be over C,B or E

After having traced the curves of probability-level,the computation of

formula (6) may be easily made with a planimeter. In that manner, and working on a much larger scale, we have arrived at the values of Table I. Of course, zone Z_0 is the one which requires a special attention within the evasion area of the target. Table I states the results obtained: first, considering only this zone; next, giving it less preponderance, and lastly making no distinction at all.

TABLE I

Total % probability of impact (P')
when the target practices evasive action, at random.

Cruiser, 33 knots - 25,000 yds.

	Target angle	Point of fire B	C	E
Computations from zone Z_0	0°	8.3	1.2	8.3
	45°	13.8	5.0	5.1
	90°	10.4	5.9	9.5
0.6 comp. from Z_0 + 0.3 comp. from Z_1 + 0.1 comp. from Z_2	0°	7.0	2.5	7.0
	45°	11.5	5.4	4.2
	90°	9.2	6.0	7.4
Equal weight for the three zones	0°	6.3	2.9	6.3
	45°	10.1	5.8	3.6
	90°	7.9	6.7	6.3

The discrimination made between the three zones of evasion area, will assist us as a starting point toward a field wherein some tactical consideration come into play.

As we already know, any loss of speed presents serious disadvantages considered from the point of view of evasive action, as for instance: a) by giving to the enemy a greater opportunity for controlling the combat range, and b) by reducing considerebly the capability of maneuver under the next salvo. As for the increase of propulsion power, we have been able to see its

relatively small effect,even in the case stated,where this increase is supposed to be instantaneous and in such a high percentage.Considering moreover that the influence of speed-changes upon the probability of impact is insignificant for most of the case (Table I),we shall carry on our discussion limiting ourselves to the effect of rudder maneuvers in evasive action.

Other factors which impose further restrictions upon the target's area of evasion,may be grouped in two cases from the point of view of their consequences:

1)Maneuver reduced in amplitude to a small change of course to either side.This is in general the case with ships in formation.

2)Such actions wherein the target may maneuver freely,but where tactical situation shows an evident preference toward effecting it on a determined side.

We want to estimate up to what point these diverse situations may be able to affect the values of Table I.In order to do this,we shall begin by observing that for each stated case,there corresponds a determined fraction of evasion area according to the division shown in fig.5.The next step,is to apply the formulas 7.If in order to simplify,we take

$$q_B \Omega = F_B$$

those relations become:

$$P_B = F_B P_B'$$

$$P_C = F_C P_C'$$

$$P_E = F_E P_E'$$

where each factor F is in essence a variable proportional to the chance of the target's making determined maneuver.

By means of a simple examination of the relative size of the three fractions of evasion area,we are going to determine the highest value that may be

expected for each one of them. As we know, applying formula 4,

$$q_C\Omega_C + q_B\Omega_B + q_E\Omega_E = 1$$

and each term will have its maximum value when the others can be neglected.

$$(q_C\Omega_C)_{max} = 1$$

or

$$(q_C\Omega)_{max} = (F_C)_{max} = \frac{\Omega}{\Omega_C}$$

Similarly,

$$(F_B)_{max} = \frac{\Omega}{\Omega_B}$$

$$(F_E)_{max} = \frac{\Omega}{\Omega_E}$$

By examining now fig. 3, bearing in mind the conditions represented by each of these cases, we are able to establish:

$$\Omega_B = \Omega_E = 2\Omega_C$$

and with this relation to get

$$(F_C)_{max} = 5$$

$$(F_B)_{max} = (F_E)_{max} = \frac{5}{2}$$

TABLE II

Maximum % probability of impact
to be expected when the target takes evasive action

Cruiser 33 knots - 25,000 yds.

Target angle	Point of fire B	Point of fire C	Point of fire E
0°	21	6	21
45°	35	25	13
90°	26	29	24

By way of comparison, we may observe in fig. 7 that if the evasive action could be totally dismissed, the impact probability upon C would in every case be over 45%.

III - Application possibilities

A) Charts of evasion

The adjusting of fire is for the purpose of correcting systematic errors, obtained through the spotting of the mean points of impact for each salvo. Let's call R_j, D_j the range and deflection spots of the mean point of impact with respect to the target. If the target has not practiced evasive action, these may be taken as errors; on the contrary, they require an adequate interpretation each time that the target has withdrawn a considerable distance away from the point of fire, during the time of flight.

Figure 9 illustrates this point, taking the case of a cruiser at 25,000 yds., with a target angle of 110°. Point C is the future position of the target, and its evasion area was oriented at an angle of 110° with respect to the line of fire. Taking C as center we add a co-ordinate system, where the horizontal lines represent distance in yards, and the vertical, deflection in mils.

If the target executes an evasive maneuver to port, we know that during the time of flight it will be separated up to a point of line "d", as a maximum. Making use of this reference, together with the observed change of course, we shall be able to estimate some point T as the position of the target at the instant of the falling of the salvo. We must locate the center of the salvo (S) with respect to this point T, and the resulting coordinates of S will be the estimated errors. For instance, in the case of fig. 9 we can see how a pair of spots "Add 300" "Left 2" are changed to "Add 200" "Right 3".

We have tried to get an easier and more practical application of these principles, with the help of the device shown in fig. 10. It consists of an upper transparent disc where the various limits of evasion are engraved, together with the corresponding references of course changes and time employed in the maneuver. Directly under this disc, there is a plate with a co-ordinate grid, of

which the vertical lines represent the direction of the line of fire.

If we orient the evasion area until the pointer of the disc is on a value corresponding to the target angle, then we shall be able to relate any one of its points to a co-ordinate system of "range and deflection", centered on the future position of the target. The range differences are expresed in yards by the horizontal lines; the deflection differences must instead be expresed in mils. Now, we know that 100 yds. in a direction perpendicular to the line of fire will be represented at each distance by a particular amount of mils. For this reason, the labels of the vertical lines are not engraved on the plate, but can be seen through orifices. By moving the distance index, we can change simultaneously all the label marks up to an adequate value.

Within the ranges at which the evasive action is feasible, we have to take into consideration only a few distinct positions for the index of range with which we can maintain a set of deflection labels sufficiently adequate.

Besides the determination of fire errors, we may suggest another form of making use of this simple computer. If we mark on the upper disc the position reached with every one of the target's evasive maneuvers, we shall get a group of points in some place within the evasion area. This record will be the graphic expression of the characteristics imposed upon the target's evasive action. The co-ordinates of range and deflection corresponding to that group at a given target angle, will give valuable information for the conduct of fire.

Finally, we wish to note that in many cases the mere inspection of the evasion area, when the lather is oriented and presented in an adequate grid of co-ordinates, will enable one to appraise the efficacy of each possible evasive action on a given course. For instance, in the case shown in fig. 10, where the target angle is 135^{o}, it can be clearly seen that there is a greater efficacy of an evasion to port because of its effects over deflection. The same conclusion may also be deduced from the chart of fig. 7 (case $A_t = 135^{o}$), by

observing the direction from C which cuts through the probability-levels in the shortest path.Such a chart will be adequate for maneuvers of small amplitude;when the target's change of course has a considerable effect over the impact probability,the charts of fig.8 will be more adequate.

B)Charts of probability-levels and tables of total probability

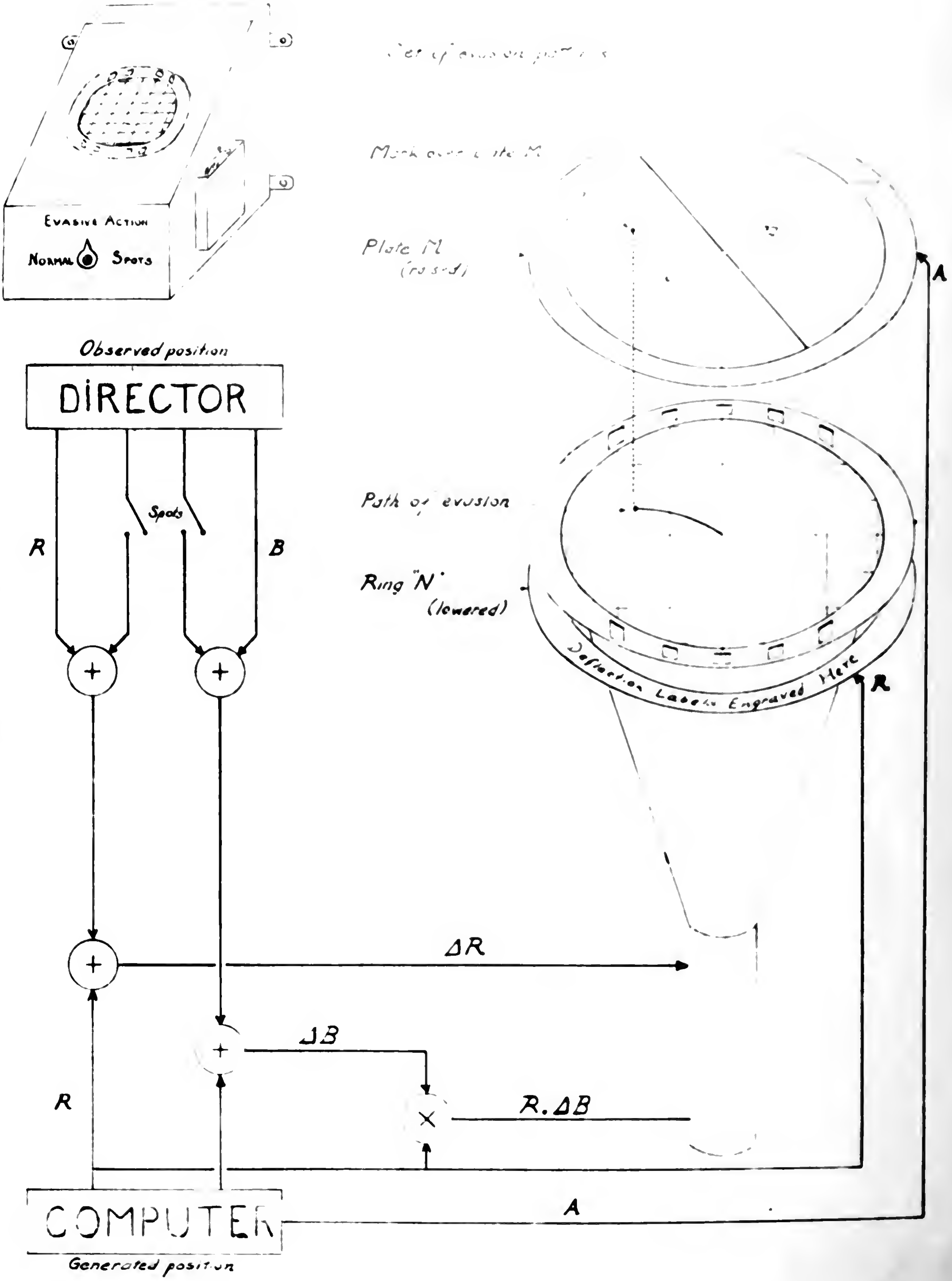
A set of charts of probability-levels,plotted for several firing ranges, will certainly be of great assistance any time we have to evaluate possibilities and efficacy of evasive actions.For instance,the charts of fig.8 correspond to a distance of 25,000 yds. and in fig.11 we can appreciate how the situation will change for a distance of 20,000 yds.,in the case $A_t = 90^o$.The total probability of impact with evasive action is now P'=15,4%,that is two and a half times greater.It can be seen how a comparative study of the probability charts and tables will afford valuable data for the planning and carrying out of certain naval actions.

According to their definition,the values of total probability are the impact percentages to be obtained after having fired a great number of salvos,which will comprise all possible reactions of the target;and in this sense,they have to agree with the average results obtained in the type of real actions for which they are computed.The principal advantage of these tables lies in providing us with comparative figures,arranged in a form which would be difficult to obtain from post-fire analysis of real actions.

IV - Apendix

A)Evasive Action Plotter.(Description and Operation).-

When a salvo is fired,the switch is turned to "EVASIVE ACTION".By doing this,a signal is receipt at the Computer,this is set at manual and the crew stands by,hands out of any crank.The computer sends up generated positions according to the last solution,and this are compared with the observed



Evasive Action
Normal
Spots
Plate M
Observed position
DIRECTOR
Spots
R
B
Path of evasion
Ring "N"
(lowered)
Deflection Labels Engraved Here
A
R
ΔR
ΔB
R
R.ΔB
COMPUTER
A
Generated position

position from the Director and radar,The range differences produce a voltage controlling the vertical displacement of the beam,and the bearing differences duly converted to deflection drive the lateral displacement of the beam.

In this way,the beam will describe in the scope any evasion of the target from its future position.The point reached at the fall of the salvo can be registered over a transparent disc,with respect to the bow of the target.For this purpose,the plate "M" is oriented with the target angle "A".

At the fall of the salvo the switch is turned to "SPOTS".In this position,the range and deflection spots are added to the observed position of the target,and the electronic beam will show in the scope the fall of the salvo in a position afected by fire errors only.

The switch is turned then to "NORMAL",and a signal at the computer will turn its crew to operation.

The plate "M",can hold a transparent disc with an arrow representing the bow of the target.This disc can be remplaced by another similar, but with a given "pattern" of evasion engraved.

B)Some cases of practical interest,when the evasive action may arise.

The evasive action perhaps be one of the more probables counter-measures to the great accuracy of modern Fire Control Systems.

The means of counteracting evasive action may be of value,checking raids of surface enemy ships against convoys.As the accuracy of submarine detection increases similar methods might be also applied to show up quickly evasive maneuvers,intended by submerged targets under attack.

The performance of effective evasive maneuvers may be of value in the following situations:

- Shore bombardment
- Keeping contact with an enemy corsair, by smaller ship. In this respect we

remember the action of the light cruisers Achiles and Ajax, against the German corsair Graff Speed, in the "Punta del Este" combat.-

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Study of evasive
action under gunfire.